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The Impact of Quality Management Tools in Municipal Water Distributors: Case of Namibia

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***Abstract*—Municipalities always face the challenge of water losses (known as non-revenue water (NRW)) due to poor maintenance of water supply infrastructure. This research investigates the impact of Quality Management (QM) Tools in the maintenance function of Namibia Municipal Water Distributors. The study reveals that 18 municipalities use an average of 8 QM tools and produce an average of 23% Non-Revenue Water (NRW), which is 3% higher than the amount recommended by the International Water Association (IWA) for well managed municipalities. Only 6 out of the 18 municipalities can be classified as well managed. The study shows that the application of QM tools is still low, considering that there are over 100 available QM tools. Surprisingly, the study shows that user friendliness has little influence on tool adoption, contrary to the initial hypothesis. QM tools are adopted because they are perceived useful. It is concluded that the application of QM tools helps to reduce the generation of NRW. Furthermore, the study finds that there is a marginal negative correlation between the use of QM tools and the generation of NRW. This confirms that the application of QM tools has a positive impact on the reduction of NRW generation.**

Keywords-quality mangement tools; non-renevue water; municipal water distribution; Namibia

I. INTRODUCTION

Maintenance of water networks and water supply in general is a complex arrangement of different factors, like transport and distribution [1]. Within this arrangement, pipe networks represent one of the largest infrastructure assets of industrial society. The management of potable water networks encompasses all activities principally concerned with the supply of water from the outlet of the water distribution reservoir to the customers' taps; and all related functions, including water resources provision, water treatment, customer relations, business planning, human resources and information services [1][2]. Once a distribution system has been properly constructed and placed in service, routine maintenance should be conducted to monitor the system's performance and identify repairs as needed. Maintenance will maintain the water system operating at optimal performance and maximize the full life expectancy of the system [2].

Selecting a suitable maintenance strategy for a water distribution system is a difficult problem due to a large number of system components, e.g. pipes, pumps, valves, meters, etc.; dynamic evolution of the failure mode of a deteriorating water pipe, the existence of a certain degree of coupling among the various system components, limited resources available for maintenance activities; and the associated difficulty in quantifying many of the benefits and costs. The problem has often been treated as a complex optimization problem with several possible objectives used in isolation or combined, e.g. maximization of reliability, minimization of downtime and the minimization of total maintenance costs. Many authors have described different strategies for maintenance management. Four basic types of maintenance strategies are can be applied by distribution network service providers, including corrective maintenance, preventive maintenance, predictive maintenance, proactive maintenance [1-6].

Current studies have shown that it is an irrefutable reality that construction of maintenance free water supply infrastructure in Namibian Municipalities is not feasible. The reality is that all the elements and components that make up water supply infrastructure deteriorate with time due to inherent defects in design, construction, environmental agents and water supplying activities. Hence, without maintenance, water infrastructure becomes inefficient and unreliable over time. As more maintenance work is needed on ageing infrastructure to ensure their continued usefulness, frequent repair of critical components is expected. Under this scenario, water distribution infrastructure maintenance becomes a significant business activity. Failure of water supply infrastructure often results in the generation of Non-Revenue Water (NRW) which subsequently leads to loss of revenue. This is an undesirable trend. As stated in [1], scarcity is fast becoming one of the most crucial challenges of our time. Small increases in global temperatures can further constrain water availability. Since maintenance costs form an integral part of the total operating costs, municipalities are constantly sourcing for cost-effective and reliable maintenance methods. To this end, the application of Quality Management (QM) principles could be useful. QM tools are generally used to facilitate positive change and improvement [2] [7-13]. QM principles, techniques, processes, and best practices have been proven effective in improving maintenance [3]. However, past studies tend to focus mainly on the use of QM tools in production plants [4-6]

According to Quality America, Inc., there are close to 100 QM tools and these come in various forms, such as check lists, charts and graphs, diagrams and other analysis tools [5]. QM tools help Municipal Water Distributors to identify, analyze and assess qualitative and quantitative data that is relevant to the maintenance of their water distribution infrastructure. The challenge however is to identify QM tools which improve maintenance of municipal water distribution infrastructure while also reducing the generation of NRW. It is clear that these domain specific QM tools would significantly possess appealing applicability because each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks [6] [7] [9].

II. Research Aim and Objectives

The purpose of this study was to investigate the application and the impact of QM tools in the maintenance of municipal water distribution infrastructure in Namibian. The objectives of the study are as follows:

1 To identify QM tools used by Namibian Municipal water distributors.
2 To investigate the themes, similarities, and differences in the use of QM tools across the water distributors.
3 To investigate the criteria under which QM tools are selected and applied.
4 To investigate the extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW.

In order to achieve the abovementioned objectives, the following hypotheses were tested:

H1: User friendliness will be a better predictor of tool selection over functionality.
H2: The application of QM tools has positive impact on the reduction of generation of Non-Revenue Water.
H3: The quantity of water supplied to a municipality, has no effect on the volume of NRW produced.

III. Research Methodology

A. Indentification of QM Tools Used

To identify the QM tools used by Namibian Municipal water distributors, maintenance departments of 18 municipal water distributors of Namibia were interviewed. In-depth interviews were used as the primary data collection method so as to get the richest data and details on the subject matter. On the other hand, document review and observations were used for secondary data collection. Document review and observations were used to provide a holistic perspective, and to understand the context within which maintenance projects are handled by the Municipal Water Distributors. This also enhanced further understanding of the issues that the participants may not be aware of or are unwilling or unable to discuss frankly in an interview.

B. Themes, Similarities, and Differences in the Use of QM Tools

Qualitative and quantitative data from 18 Municipal Water Distributors had to be analyzed. Based on the findings from the literature review, this study utilized cross case analysis as the study method. Based on the QM tools used and the NRW produced the municipalities were classified into 4 case categories, that is, Case A, B, C and D as shown in the Table 1, where, for instance, Case A refers to municipalities that produce more than 20% NRW, while employing seven or more quality management tools, and Case B refers to municipalities that produce less than 20% NRW while employing seven or more quality management tools, and so on.

TABLE I. CASE ORGANIZATION PROTOCOL

Case	Number of tools used	Quantity of NRW
A	≥7	> 20%
B	≥7	< 20%
C	< 7	< 20%
D	< 7	> 20%

The quantity of seven tools was selected because many writers have stated that there are seven basic tools used to solve the vast majority of issues including maintenance work [7]. The basic tools are Fishbone or Ishikawa Diagram, flow charts, Scatter diagram, Pareto Chart, Check sheet, Control Chart and Quality tools. These tools are called basic because they are suitable for people with little formal training in statistics and because they can be used to solve the vast majority of issues [8]

C. Criteria Under Which QM Tools Were Selected

The independent variables which may affect the selection of QM tools by the Namibian Municipalities were measured by attitudinal statements. The Likert scale was used in the questionnaire, during the survey research. Based on previous literature review and the case study, the two reasons for selecting a tool were either it is user friendly or it is perceived as being useful therefore when responding to a Likert questionnaire item, respondents had to specify their level of agreement with the following two statements;

1 I am able to use this specific tool without much support – it is user friendly.
2 The results of using this tool are measureable - it is useful

Each statement was measured by a 5-point Likert-type scale that is, 1: Strongly disagree; 2: Disagree; 3: Neither agree nor disagree; 4: Agree; and 5: Strongly agree. Regression analysis was used to determine the relationship between the variables for all municipalities.

D. The Impact of QM Tools and the NRW Generation

To investigate the extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW, a quantitative study which utilizes statistical data collected from Namibian Municipalities was used. Regression analysis was to study the relationships between the quantity of water supplied, the number of tools used, and the average NRW produced by the municipality.

E. Limitations of the Study

The limitations of the research are as follows: (i) only water supply infrastructure located within Namibian Municipalities will be employed as case studies; (ii) the research focuses on municipalities as defined by the Namibian Local Authorities Act No. 17 of 2002 [9]. The sample size will consist of 18 Municipalities; (iii) the study will also be limited to the main potable water supply infrastructure such as pipelines, pumps and motors, i.e., land, vehicles, intangible assets and any other assets that are not part of the water supply network do not form part of the study.

IV. RESULTS AND DISCUSSIONS

A. QM Tools Used by Municipal Water Distributors

Table II presents the results of the research in respect of the number of tools that we employed. Interesting observations were noted from the results.

TABLE II. DESCRIPTIVE DATA ON QUANTITY OF TOOLS USED

Parameter	Value	Parameter	Value
Mean	7.944444444	Kurtosis	-0.19616584
Standard Error	1.474117044	Skewness	1.078244875
Median	4.5	Minimum	2
Mode	4	Maximum	22
Standard Deviation	6.25414895	Sum	143
Sample Variance	39.11437908	Count	18

The average number of tools applied by the Municipalities was 7.94 tools with a standard error of 1.474. The maximum number of tools used by a single municipality was found to be 22 and the least was 2. The total number of tools used was 143, with a skewness of 1.078 which means the data is skewed to the right as the mean is greater than the mode. The data has a Kurtosis of -0.1961. The sample variance was 39.11, with a standard deviation of 6.25.

Table III reflects the tools used by Namibian Municipalities together with the relative frequency of use. The most commonly used tools were histograms (100% of the respondents), brain storming (100% of the respondents), flow charts (89%), and scatter diagrams (61%). The least commonly used tools are FMEA, condition monitoring and tree diagrams which are utilized by only 6% of the respondents. 33% of the respondents use the Gantt chart, Control charts, Net Present Value calculations, benchmarking and process maps. About 50% of the respondents use the check list.

TABLE III. TOOLS AND THEIR FREQUENCY OF USE

Groups	*Frequency of Use*	*Respondents (%)*
Critical path method	7	39%
Gantt chart	6	33%
Checklist	9	50%
Condition monitoring	1	6%
FMEA	1	6%
Tree diagram	1	6%
Histogram	18	100%
Pareto diagram	1	6%
Control charts	6	33%
Net present value	6	33%
Gantt chart	3	17%
Bench marking	6	33%
Flow charts	16	89%
Check sheets	6	33%
Run charts	6	33%
Root cause analysis	3	17%
Brain-storming	18	100%
Use process maps	6	33%
Housekeeping	4	22%
Quality control audits	3	17%
Line graph	5	28%
Scatter diagrams	11	61%

Figure 1 shows the municipalities together with the number of tools that they use. Windhoek Municipality utilizes the highest number of tools while Rundu utilizes the least of them all. The NRW produced by each municipality was determined by subtracting known water uses from the total water supplied to the distribution system. This information was obtained from interviews and cross checked using the audited financial statements of each respective municipality.

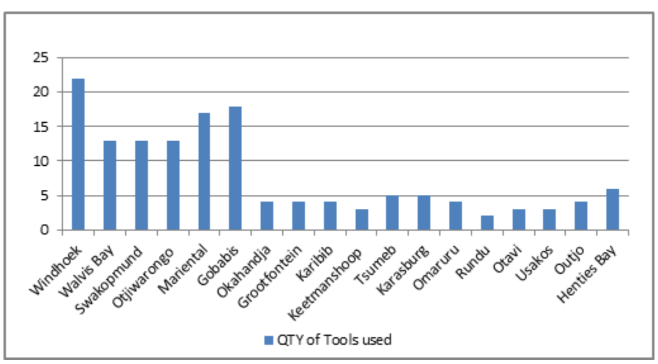

Figure 1. Municipalities and the number of tools used

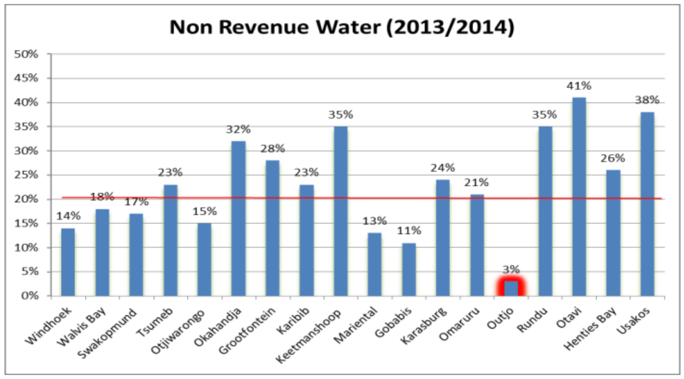

Figure 2. Municipalities and the amount of NRW generated

Figure 2 shows the municipalities and the respective NRW generated. The average quantity of NRW was 23% with a standard error of 2%. The total quantity of NRW produced by the municipalities was 41.2%, with a skewness of 0.079 and a Kurtosis of -0.6836. The highest percentages of NRW were recorded at Otavi and Keetmashoop with 41% and 35%, respectively. The least NRW was recorded at Outjo, Gobabis, and Windhoek which have 3%, 11% and 14% respectively. No information could be obtained with regard to the NRW generated by the Outjo municipality.

B. Themes, Similarities, and Differences in the Use of QM Tools

Qualitative and quantitative data from the 18 municipals were analyzed. Figure 3 shows the results of the study based on the cross case analysis.

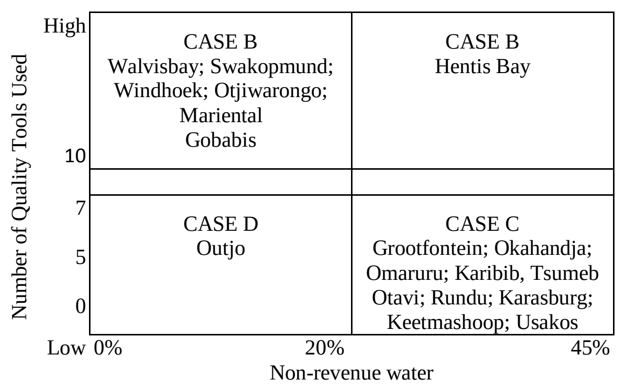

Figure 3. Case organization chart

C. Criteria Under Which QM Tools Were Selected

The regression analysis was used to determine how the independent variables, that is, user-friendliness and usefulness, are related to the dependent variable which is the Quantity of QM tools selected. The relationship between the variables may be written in the following model:

$$Q_1 = 2.46 + 0.085\, t_1 + 0.126\, t_2 \qquad (1)$$

where, Q_1 = Quantity of QM tools selected; t_1 and t_2 represent user friendliness and usefulness, respectively.

Table IV presents a summary of the regression results obtained regarding the QM tools used and user-friendliness and usefulness.

TABLE IV REGRESSION RESULTS FOR QM TOOLS SELECTED AND USER-FRIENDLINESS AND USEFULNESS

Regression Statistics	
Multiple R	0.932079481
R Square	0.868772159
Adjusted R Square	0.854958702
Standard Error	1.948139447
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	477.3903012	238.6951506	62.89317437	4.18068E-09
Residual	19	72.10969881	3.795247306		
Total	21	549.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.461364749	0.650280302	3.78508274	0.001251668	1.100312434	3.822417064
User friendly	0.085433123	0.036662688	2.330247085	0.030967569	0.008697234	0.162169011
Usefulness	0.126315342	0.044850232	2.816381031	0.011022918	0.032442728	0.220187956

From the model, the largest beta value was useful tools with a value of 0.126, which means that this variable makes the strongest contribution to explaining the selection of tools by the municipalities, when all the other values in the model are controlled for. The user friendly contribution is lower (0.085), meaning that it does not play as big role as being perceived to be useful.

Hypothesis H1 predicted that user friendliness will be a better predictor of tool selection over usefulness. The coefficients from the study results however show contrary results.

The t-stat was used to validate the outcome results of the model. Comparing the results between high users of QM tools and low users of tools, which are Case C and Case B in this study, the results shows that the selection of user friendly tools by high users of QM tools is higher than those of low users. High users of QM tools posted a t-stat of (1.59) against a t-stat of (0.33) by low users. However when comparing the selection of tools for being useful, lower users of QM tools posted a t-stat of (1.56) against a t-stat of (1.11) by low users. The selection of tools according to how they are perceived to be useful is higher for low QM tool users than for high QM tool users."

D. The Impactof QM Tools and the NRW Generation

Regression analysis was carried out for quantity of water supplied, the number of tools used, and NRW produced was done. Table V presents a summary of this data.

TABLE V WATER SUPPLIED, TOOLS USED AND NRW PRODUCED

Water System	Input Volume.	Authorised Consumption	Water Loss	Loss %	Tools Used
Windhoek	18,842,529.0 0	2,637,954.06	16,204,574.94	14%	22
Walvis Bay	5,693,903.00	852,873.00	4,841,030.00	15%	13
Swakopmund	4,384,736.00	743,931.00	3,640,805.00	17%	13
Tsumeb	2,793,523.00	629,090.00	2,164,433.00	23%	5
Otjiwarongo	1,347,300.00	205,069.00	1,142,231.00	15%	13
Okahandja	1,294,181.00	414,137.92	880,043.08	32%	4
Grootfontein	162,388.62	45,468.81	116,919.81	28%	4
Karibib	304,055.19	69,932.69	234,122.50	23%	4
Keetmanshoop	1,704,882.00	598,642.00	1,106,240.00	35%	3
Mariental	878,972.00	113,164.00	765,808.00	13%	17
Gobabis	802,690.00	90,761.00	711,929.00	11%	18
Karasburg	250,323.00	47,000.00	203,323.00	23%	5
Omaruru	634,328.00	132,845.00	501,483.00	21%	4
Outjo	846,595.00	25,770.00	820,825.00	3%	4
Rundu	2,708,874.00	938,912.00	1,769,962.00	35%	2
Otavi	276,677.00	112,515.00	164,162.00	41%	3
Henties Bay	500,274.00	128,823.00	371,451.00	26%	6
Usakos	372,469.00	142,179.00	230,290.00	38%	3

The correlation coefficient between the number of tools used by a municipality and the NRW generated was found to be -0.665. It is evident therefore that the number of tools employed by a municipality and the generation of NRW have an inverse relationship due to the negative sign of the coefficient. This means that as the number of tools used increase, the amount of NRW reduces. However, since the coefficient is not close to a unity (1), it means that there is marginal correlation between the number of tools used and the NRW generated since this value was found to be -0.665. Table VI presents the regression results for user friendliness and usefulness.

TABLE VI REGRESSION RESULTS FOR NRW PRODUCED AND USER-FRIENDLINESS AND USEFULNESS

Regression Statistics	
Multiple R	0.665374771
R Square	0.442723586
Adjusted R Square	0.368420064
Standard Error	0.082287966
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.080691151	0.040345576	0.012460342	Regression
Residual	15	0.10156964	0.006771309		Residual
Total	17	0.182260792			Total

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.318825815	0.032456424	9.823196053	0.249646585	0.388005	Intercept
Methods	-0.01281686	0.004067419	-3.15110395	-0.02148636	-0.004147	Methods
Input vol	4.93426E-09	5.81942E-09	0.847895003	-7.46955E-09	1.733E-08	Input vol

The relationship between the variables may be written in the following model:

$$Q_2 = 3189 - 0.0128\, x_1 + 4.9343\, x_2 - 0.9\times10^{-9}\, q \qquad (2)$$

where, Q_2 = NRW produced; x_1 and x_2 represent number of methods employed, respectively, and q is the quantity of water supplied to a system.

E. Futhere Discussions

The largest beta value was Number of methods employed with a value of 0.012 this means that this variable makes the strongest contribution to explaining the Production of NRW by Namibian municipalities, when all the other values in the model are controlled for. The quantity of water supplied to a system’s contribution is lower (4.93E-9), meaning that it does not play a significant role as compared to the number of methods employed.

The negative correlation confirms that the application of QM tools has a positive impact on the reduction of the generation of Non-Revenue Water, because as the number of tools employed by a municipality increases, the generation of NRW decreases. These results are in agreement with the correlation analysis and the second Hypothesis of this study.

Hypothesis H2 states that the application of QM tools has a positive impact on the reduction of the generation of Non-Revenue Water.

The null hypothesis would be that the percentage of NRW produced by municipalities which use QM tools and those that don’t is the same, holding all the other relevant factors constant. Since the results show a p-value on the application of tools is less than 0.05, the study rejects the null hypothesis and concludes that the application of QM tools has a positive impact on the reduction of the generation of NRW. The *p*-values evaluate how well the sample data support the argument that the null hypothesis is true.

The correlation results mentioned above also provide clarity to Hypothesis 3. Hypothesis H3 states that the quantity of water supplied to a municipality, has no effect on the volume of NRW produced. The null hypothesis would be that the percentage of NRW produced by municipalities with high water demands is the same as that from municipalities with low water demand, holding all the other relevant factors constant.

The Namibian municipalities can use the models to iterate the number of tools needed to limit the NRW produced for their water demands. It should be noted however that the QM tools will not reduce the generation of NRW on their own, physical maintenance work must still be done on the infrastructure. This finding fulfills objective number 6 which seeks to propose a QM implementation strategy that can be adopted by Namibian Municipal Water distributors for improved maintenance of infrastructure and reduction of NRW

V. CONCUSIONS

The research investigated the impact of Quality Management Tools & Techniques in the Maintenance function of Namibian Municipal Water Distributors. Based on the findings of the research, it is concluded that the application of QM tools in the maintenance function of Namibian water distribution infrastructure helps in reducing the generation of NRW and that Statistical literacy is synonymous with the use of QM tools.

The study found that there is a marginal negative correlation between the use of QM tools and the generation of NRW. The negative correlation confirms that the application of QM tools has a positive impact on the reduction of the generation of Non-Revenue Water. This is interpreted to mean that as the number of QM tools employed to analyze maintenance data by a municipality increases, the generation of NRW by the Municipality decreases. However for the tools to be effective, they should cover various applications such as problem identification, data analysis, process analysis, decision making, planning, quality control and statistical process control, as demonstrated by Namibian Municipalities which produce low volumes of NRW. Arbitrary selection and use of QM tools with limited applications does not yield desired results as demonstrated by the high quantities of NRW generated by the poorly managed Municipalities. Contrary to what was hypothesized, it can also be concluded that the Namibian Municipalities select and use QM tools because they perceive them to be useful. It was initially hypothesized that Namibian Municipalities select and use tools because they perceive the QM tools to be user friendly. The study found that the amount of NRW produced by Namibian municipalities can be expressed by a regression model.

However the model is limited due to the fact that it does not specify the exact tools to be used or added. Furthermore, Statistical literacy can be identified as playing a significant role in the selection and application of QM tools as demonstrated by Municipalities which produce low volumes of NRW. These municipalities recruit Maintenance managers who have an engineering background and knowledge in QM tools and techniques, while Municipalities which produce high quantities of NRW recruit Maintenance managers who have no engineering background and have no knowledge in QM tools and techniques. The research also concludes that, the application of QM tools in Namibian municipalities is still under exploited considering that there are over 100 QM tools available for use, while the 18 Namibian municipalities use an average of 8 QM tools.

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